The background of the entire page is a vibrant illustration of Earth from space, showing swirling blue and white clouds. In the lower right, the Space Station Freedom is depicted in orbit, with its complex structure of modules and large solar panel arrays clearly visible. The station is illuminated by a bright light source, creating a strong contrast with the dark space. The title 'Space Station Freedom' is written in a large, elegant, white serif font, and 'Gateway to the Future' is written below it in a smaller, similar font. Both are centered in the upper half of the page.

# *Space Station Freedom*

## *Gateway to the Future*

(NASA-NP-137) SPACE STATION  
FREEDOM GATEWAY TO THE FUTURE  
(NASA) 30 p


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**NASA**





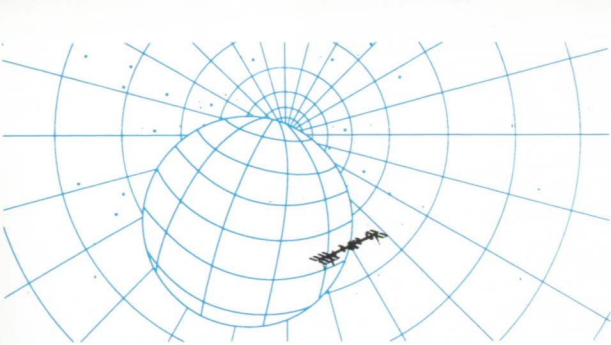
As the century turns, Space Station Freedom will open a new era of exploration. Our first inhabited outpost on the frontier of space will be a place to live, work and discover. Experiments conducted on Freedom will advance scientific knowledge about our world, our environment and ourselves. We will learn how to adapt to the space environment and to build and operate new spacecraft with destinations far beyond Earth, continuing the tradition of exploration that began with a journey to the Moon. What we learn from living and working on Freedom will strengthen our expertise in science and engineering, promote national research and development initiatives and inspire another generation of Americans to push forward and onward. On the eve of the 21<sup>st</sup> century, Space Station Freedom will be our gateway to the future.





*Great Nations Dare to Explore: Space Station Freedom*





## *Gateway to Space*

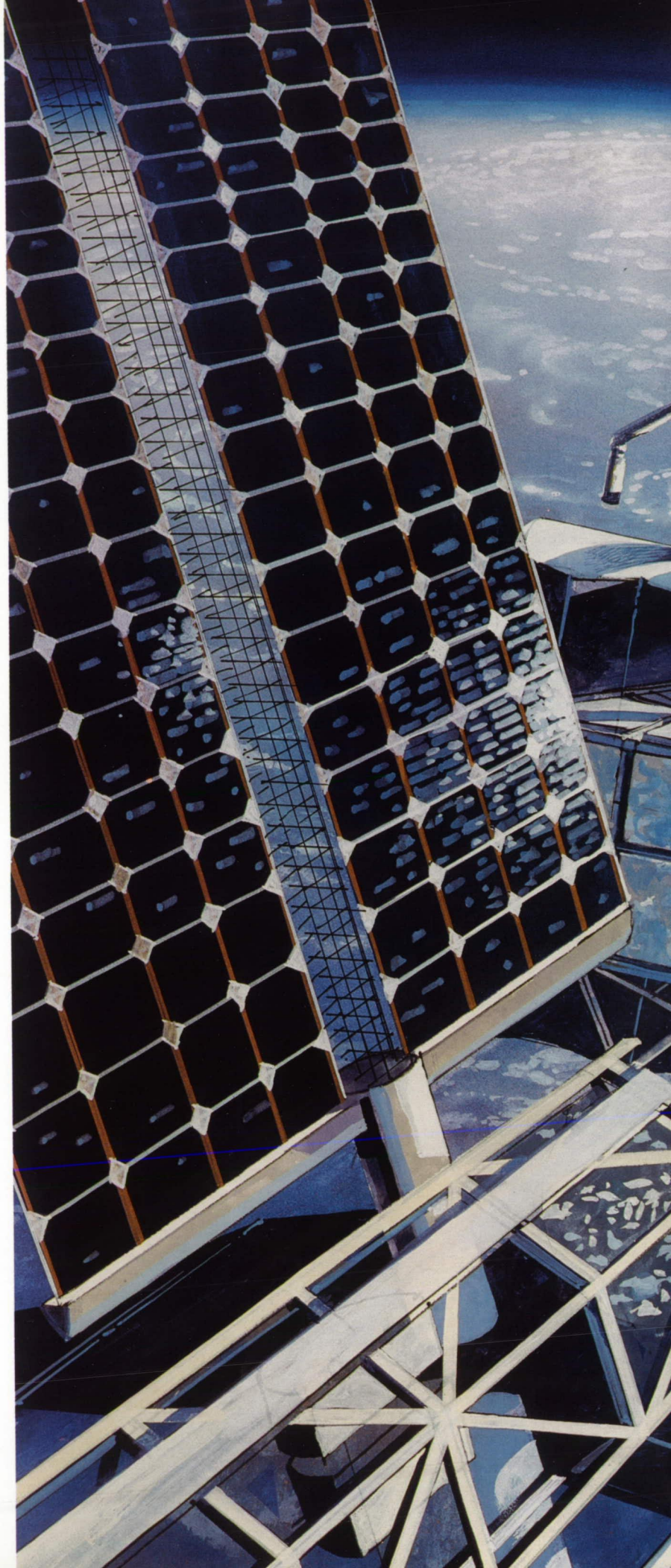
Space Station Freedom is the most complex engineering feat in history, the largest spacecraft ever built and the greatest international space venture ever undertaken. It will be used to conduct life sciences and microgravity research, technology development and commercially oriented research. Space Station Freedom is being designed and built by a partnership between the U.S. and Japan, the member states of the European Space Agency and Canada.

The station has four pressurized modules attached to a long truss. Three modules are international laboratories and one module provides living and sleeping quarters for the crew. The Space Shuttle docks with the station at one of the ports connected to the modules. Solar power systems and utility equipment are mounted along the station's truss, along with small observational instruments.

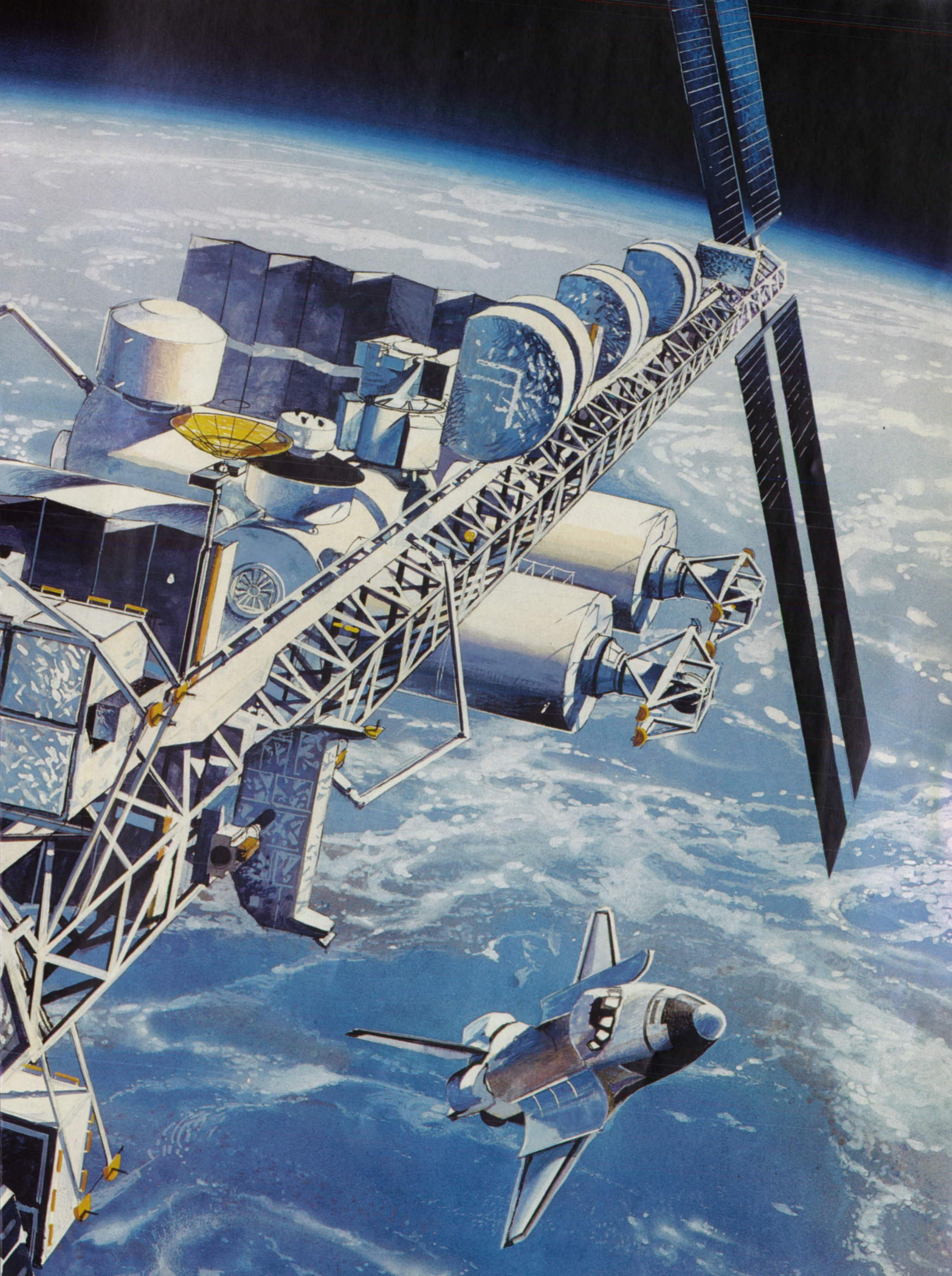
According to a carefully planned construction schedule, Space Station Freedom's components are being built, tested and integrated on the ground and will be assembled in space over a period of four years. The Space Shuttle will transport these components into orbit where they will be installed by astronauts with assistance from robotic devices. Initially, the crew will work from the Shuttle to assemble the station and will depend on the Shuttle for their life support. As modules, supplies, experiments and systems arrive at the emerging station, it will become a work place and home in space for the international crews.

Four astronauts from the U.S. and the partner nations will live and work together on the station for rotations lasting up to six months. The crew will be expanded to eight astronauts after the year 2000. The crews will be directed by scientists and technicians on the ground to perform planned experiments. The research results are expected to yield new discoveries, innovations, products and processes that will improve the quality of life on Earth and establish our leadership in space science and exploration.

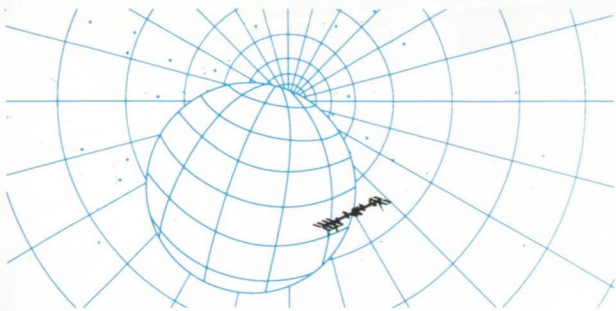
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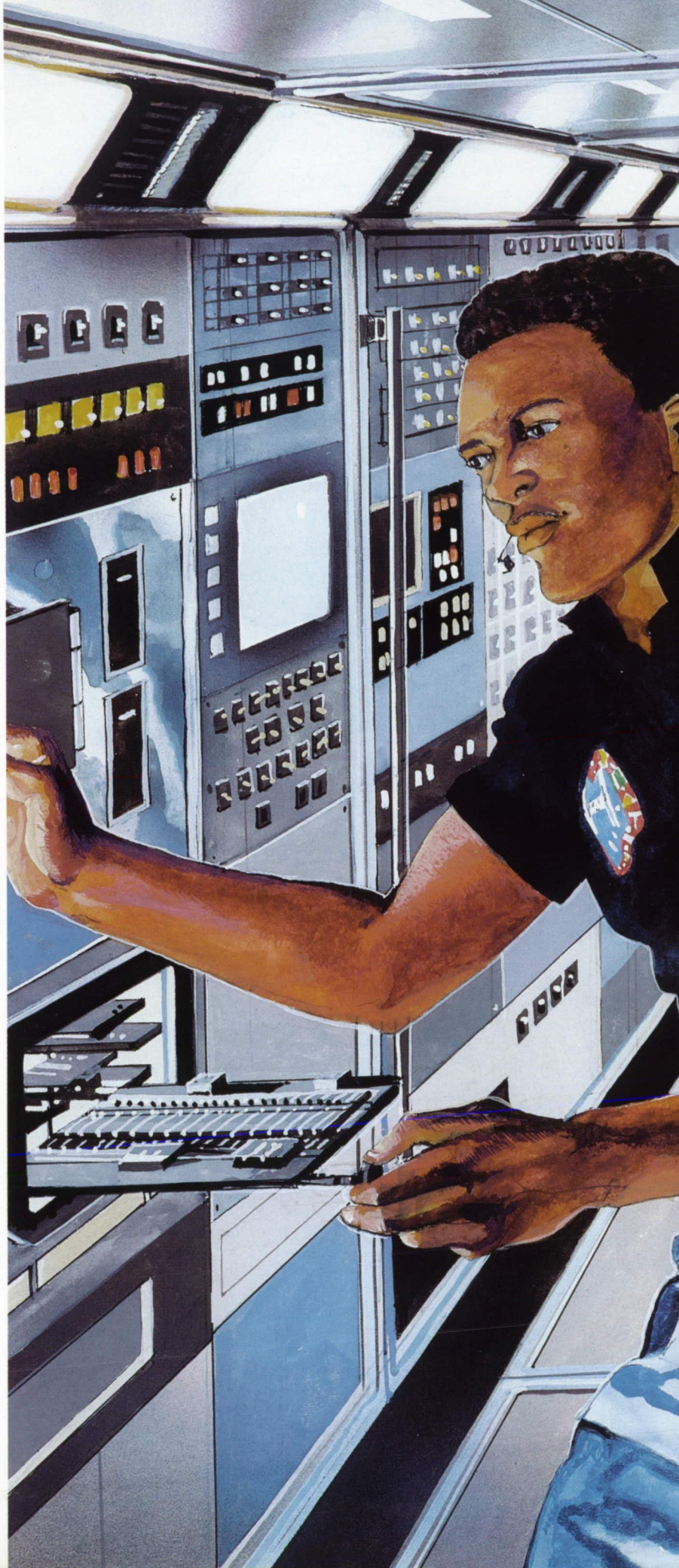
## Gateway to Research

Freedom's three pressurized laboratories are outfitted with state-of-the-art equipment and facilities to accommodate user experiments. The inside of Space Station Freedom resembles a modern laboratory on Earth, even though there is no "up" or "down" in near-weightless space. Payloads, computers, equipment to control the air and temperature, as well as tools, spares and utility equipment, are installed in modular racks that form the walls, ceiling and floor of the laboratories. Foot restraints stabilize the astronauts while they work.

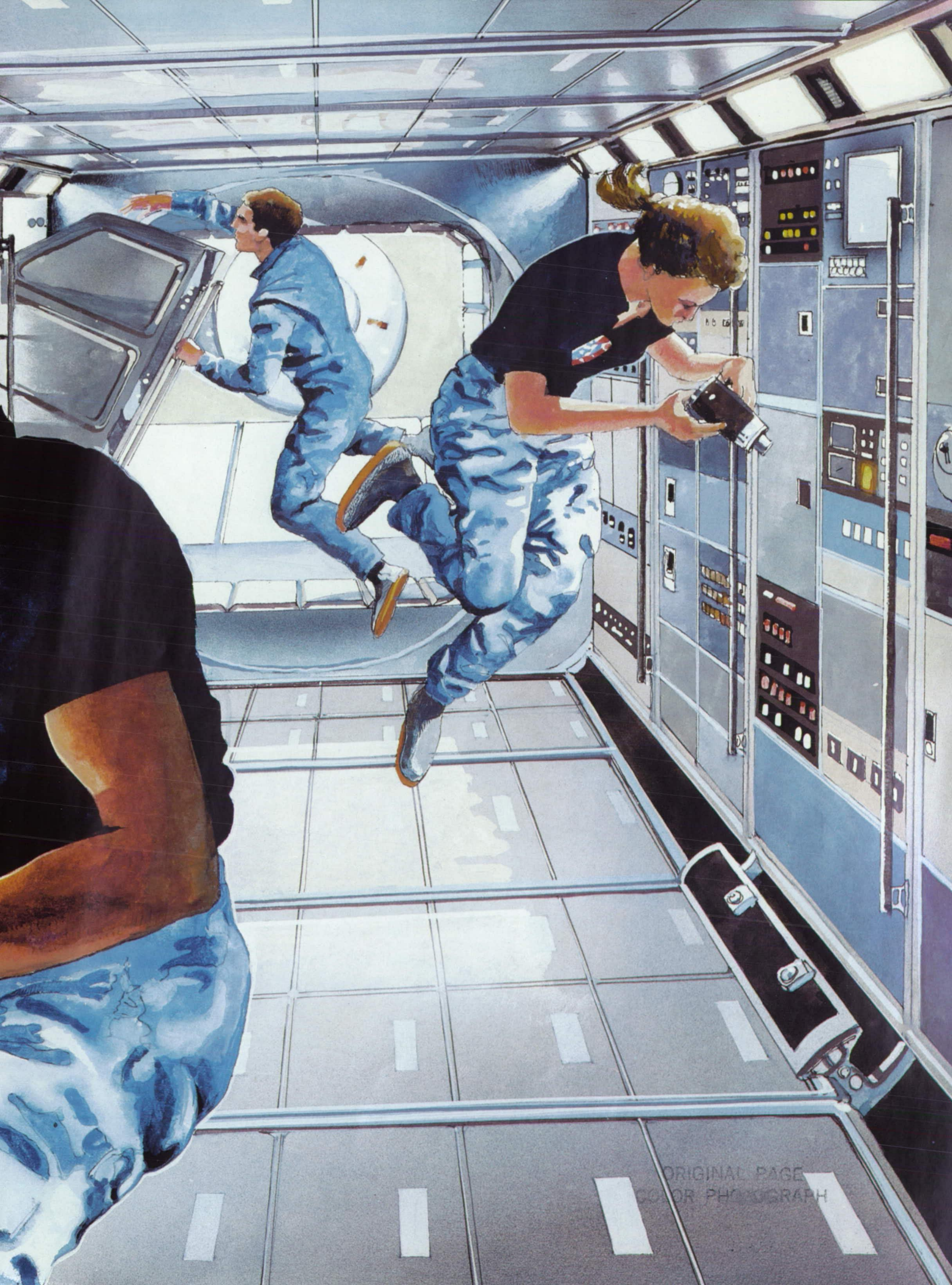
A satellite communications system keeps the crew in touch with researchers on the ground who guide the astronauts in operating and monitoring the payloads. Some payloads operate for long periods, while others are turned on and off by the crew within minutes or hours. One advantage of human-assisted space research is the astronauts' ability to respond to unexpected events with creativity, dexterity, perception, reason and judgment. Their immediate responses can enhance the value of the experiments and, in some cases, may lead to important scientific breakthroughs.

In this scene from a typical day on Freedom, the international crew is at work in the U.S. Laboratory. The astronaut in the foreground prepares a tray of fluid samples for experimentation in the protein crystal growth facility. The astronaut at the right removes a vial of plant cells from another experiment. In the background, the astronaut lowers a rack for inspection and servicing.

The crews receive more than 18 months of training to learn how to operate the station's systems and the experiments for their missions. In space, the astronauts work six days a week, nine hours a day, moving freely between the three laboratories to monitor the ongoing experiments. On their time off, they reside in the Habitation module, or Hab, which has all the features of a compact, modern home and is located next to the U.S. Lab. In the Hab, the astronauts can eat, exercise, bathe, read, sleep, relax and, as necessary, receive medical care. Their safety, comfort and well-being are important considerations in the design of Space Station Freedom.

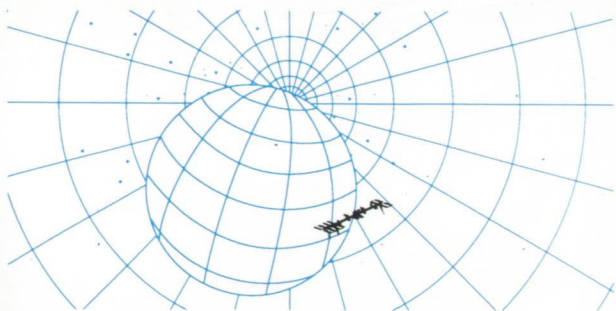






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## Gateway to Discovery

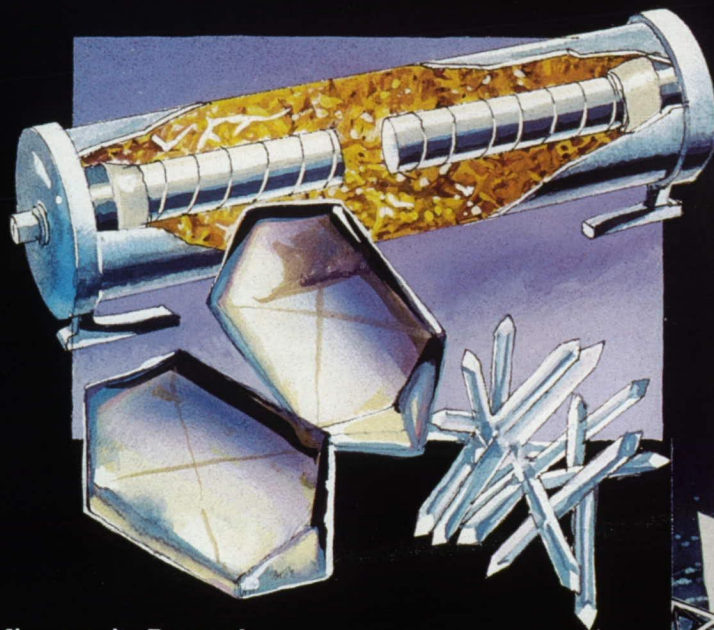
Space has been a place of bountiful discoveries for over three decades, providing a unique research environment that cannot be replicated on Earth. Without the effects of gravity, materials and processes behave differently, allowing them to be studied more fully; without the distortion caused by Earth's atmosphere, celestial bodies and phenomena can be observed with clarity and precision. Space Station Freedom will provide unparalleled opportunities for researchers to take advantage of the space environment.

The microgravity environment of space allows physical processes to be observed more clearly. Materials mix more evenly, fluids form perfectly round spheres, and crystals can be grown with fewer impurities or defects. By studying materials on Space Station Freedom, we may learn how to produce better medicines on Earth, lighter building materials, advanced electronic devices and new metals, alloys, glasses and ceramics for industrial applications.

Gravity plays a role in the development of most, if not all, biological systems. The chance to examine microorganisms, plants, animals and humans in space for long periods is unprecedented in the history of biology. Life sciences research on Space Station Freedom is expected to hasten improvements in medical procedures and equipment and increase our understanding of human diseases, aging and immune functions. This research will also help us understand the physiological and psychological effects of extended space flight on human beings.

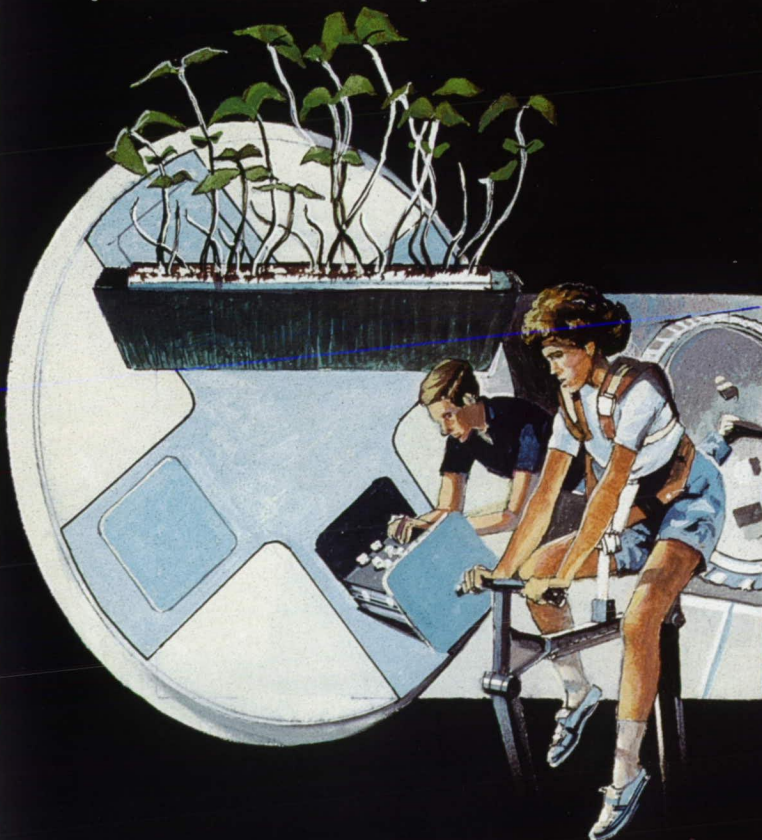
From living and working on the station, we will learn how to manage the operation of large, complex spacecraft and how to adapt to the harsh space environment. New systems for waste management, water reclamation and food production will be tested. Artificial intelligence systems and the dynamics of locomotion and manipulation in space will be tested, to aid innovation for future space missions.

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## Microgravity Research

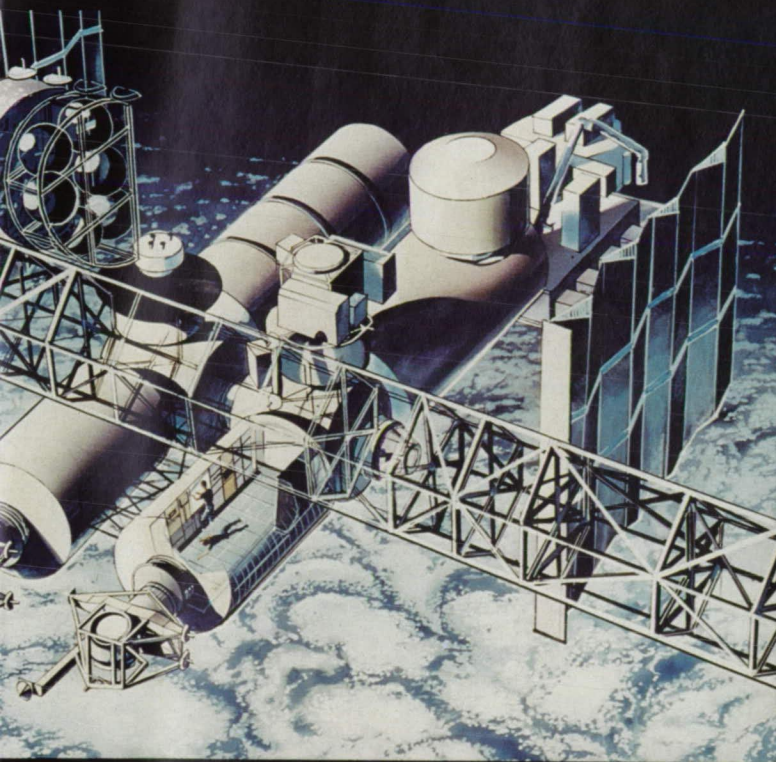
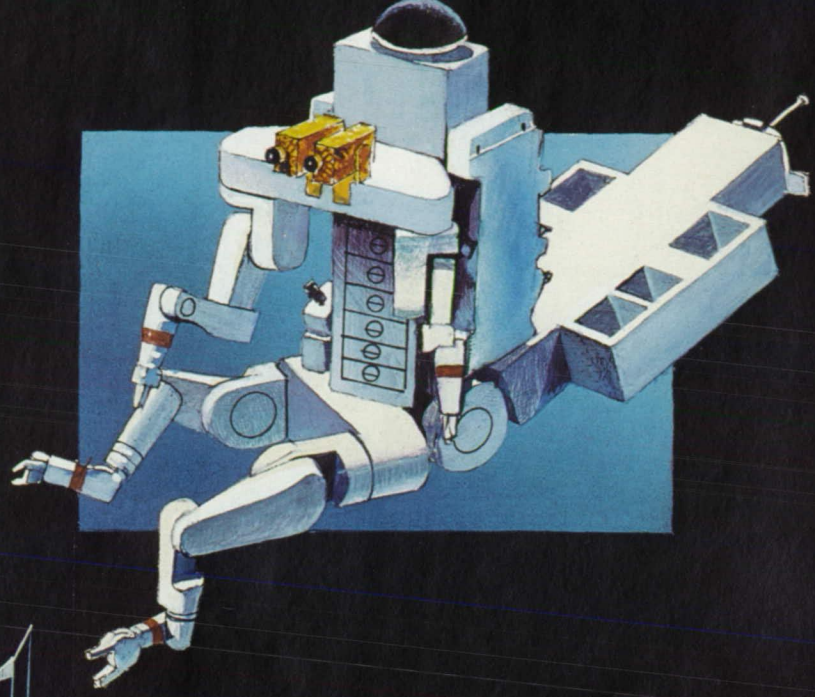
The microgravity environment of space enables materials to be processed in ways that are not possible on Earth. Experiments to produce perfectly formed, defect-free protein crystals like these will be conducted on Space Station Freedom. When the crystals are returned to Earth, the study of their structures and compositions could lead to improved pharmaceutical and electronic products.





**Technology**

Data on the dynamics of large structures will be collected, and the long-term performance in space of microelectronics, paints, thermal materials and sensors will be studied. New processes for trash recycling, chemical separation and purification may be identified. Robots similar to this model will be used outside Space Station Freedom to perform risky tasks previously performed by astronauts.



**Observations**

Freedom will provide a vantage point to observe the heavens and Earth. Observations from Freedom could contribute to our understanding of the origin and fundamental laws of the universe.

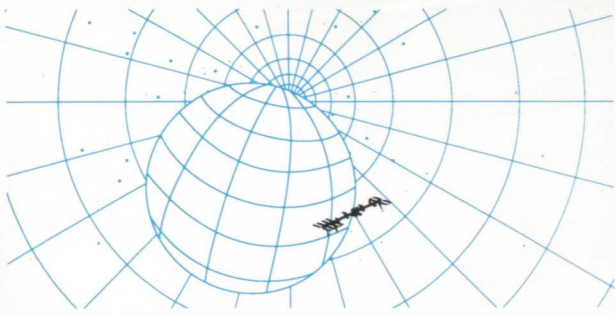


**Life Sciences**

Life sciences experiments will focus on biological processes and the effects of gravity on reproduction, development and evolution. These studies may increase our understanding of the causes and treatments of high blood pressure, immune deficiencies and orthopedic disease. A large centrifuge simulating different levels of gravity will test the effects of microgravity on plant and animal growth. This knowledge is crucial to any long-term space mission or a planetary base. Experiments performed on the astronauts will show the effects of near-weightlessness on the human body, especially the heart, skeleton, muscles and immune system.







## Gateway to Utilization

A Space Station Freedom user can be any individual or group, in the U.S. and abroad, who performs research on Space Station Freedom. The utilization of the station for productive research is being carefully planned now to make the actual experiment process as successful and user-friendly as possible. Users will come from the commercial sector, the technology development community and the scientific community.

NASA has established offices that foster and support research programs, select payloads and sponsor U.S. users in the areas of science, technology development and commercial enterprises. The international partners select their users according to their own policies. Operations support teams, astronauts and users will work together to ensure the successful operation of the experiments in orbit.

As the station evolves, NASA will help its user communities understand the growing capabilities of Space Station Freedom and communicate technical developments and experiment results. These activities reflect NASA's awareness of the needs of users and the importance of establishing a clear pathway to Space Station Freedom.

The science users will study areas such as fluid behavior and transport phenomena, flame propagation and the effects of low gravity on humans, animals, plants and materials. The results will expand our knowledge in such areas as crystal growth and structure, fluid mechanics, combustion phenomena, human physiology and gravitational biology. The results may aid in the treatment of human diseases and expand our knowledge of human physiology and plant development.

Technology development users will examine structures, space environmental effects, noise and vibration, energy systems, propulsion, integrated circuits, automation and robotics and life support systems. These technologies will be critical for future space missions and for innovation in Earth-based industries.

Commercial users will perform research in areas having potential applications for use on Earth and for potential production in space. Commercial experiments will focus on industrial research for the medical, agricultural and chemical industries, purification and recycling systems and food production.



By collecting and studying meteoroids and interplanetary dust particles, scientists can learn more about the evolution and composition of the solar system.

Scientific researchers will perform low-gravity experiments to gain insight into fundamental biological processes, the treatment of human disease, plant growth and development in controlled environments and the long-term effects of space travel on the human body.

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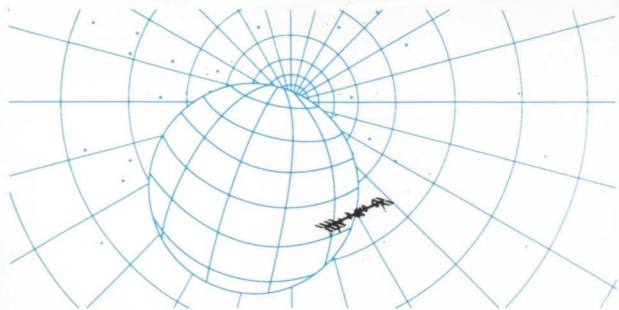




Commercial researchers plan to grow and study inorganic crystals used to improve semiconductors and materials for electronic devices.

Advanced robotic systems will assist the astronauts in performing high-risk tasks and in assembling the station. By testing new materials and structures in orbit, engineers will learn how to build very large, flexible structures in space.





## Gateway to Benefits

The primary mission of Space Station Freedom is to enable and support exploration and discovery. Space Station Freedom is essential for advancing the human exploration of space and will lead to discoveries we cannot yet imagine. As it fulfills its primary mission, Space Station Freedom will yield additional benefits.

Like our early space adventures, Space Station Freedom will stimulate the intellectual curiosity of our inventors, scientists and manufacturers and inspire the dreams of our most valuable resource—our youth. Space Station Freedom will foster significant innovation in industry, which will improve the convenience, safety and productivity of our lives. But its ability to renew interest in science and engineering education may be its most important contribution.

The U.S. is committed to the exploration and use of space for peaceful purposes. The world-class research performed on Space Station Freedom will continue the tradition of U.S. leadership in space for decades to come. It will also allow us to investigate the science and technology that underlies long-term human exploration of the solar system.

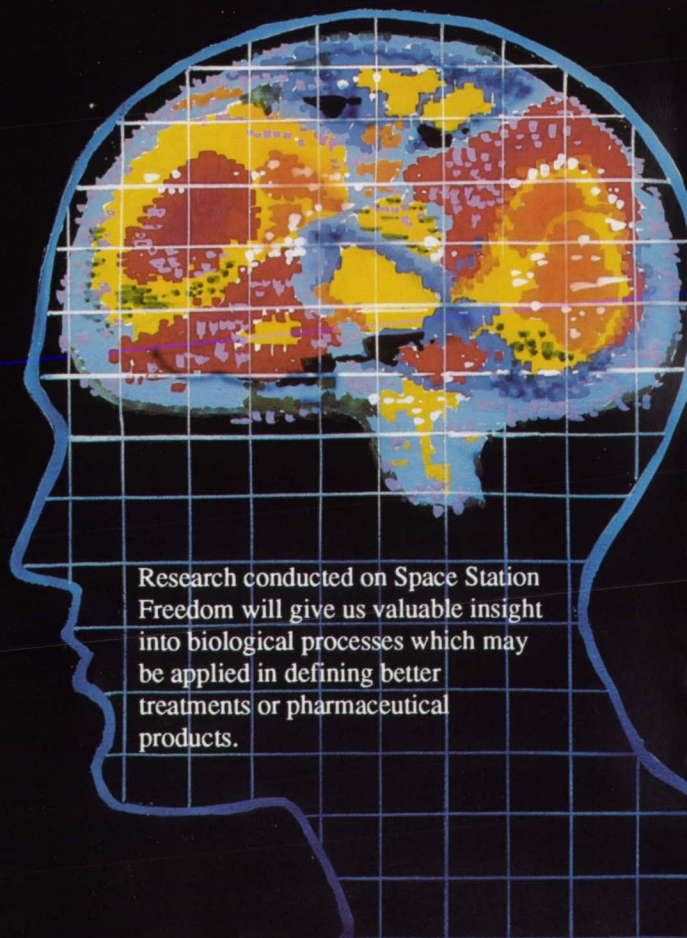
The potential of space promises countless economic benefits to all spacefaring nations. The useful products and new processes that result from space research should create new jobs in business and industry. New ventures in manufacturing, health and medicine, communications and electronics will continue to be critical to our economic competitiveness.

Internationally, Space Station Freedom is also a symbol of a cooperative and productive "global village." The alliances forged among the space organizations of the U.S., Japan, Europe and Canada have already promoted international cooperation to a new level. Space Station Freedom will strengthen international ties for future space ventures.

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The excellent research conditions on Space Station Freedom promise exciting advances in improved semiconductors, metals and alloys; medical treatments and procedures; and enhanced understanding of planetary science and the formation of the solar system.



Research conducted on Space Station Freedom will give us valuable insight into biological processes which may be applied in defining better treatments or pharmaceutical products.



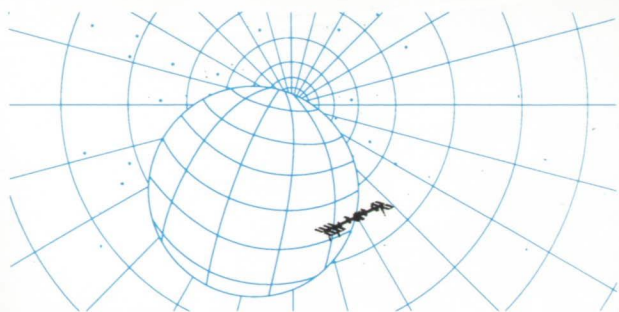


Technology experiments will enable the development of new automation systems and robotic devices.

Knowledge gained from research on Space Station Freedom may lead to better methods of growing crops on Earth.

Space Station Freedom will inspire our youth and stimulate interest in science, mathematics and engineering. A better educated work force will benefit our economy and our civil space endeavors.





## **Gateway to NASA**

***Questions concerning Space Station Freedom utilization, commercial reimbursable payload opportunities and station research capabilities can be addressed to:***

Spacelab/Space Station Utilization Program  
User Integration Division  
Code MG  
NASA Headquarters  
Washington, D.C. 20546

***For information about space station payloads, contact the office shown above or the appropriate NASA sponsor:***

### ***Science opportunities:***

Office of Space Science and Applications  
Flight Systems Division  
Code SM  
NASA Headquarters  
Washington, D.C. 20546

### ***Technology opportunities:***

Office of Aeronautics and Space Technology  
Space Technology Directorate  
Code RS  
NASA Headquarters  
Washington, D.C. 20546

### ***Commercial cooperative opportunities:***

Office of Commercial Programs  
Commercial Flight Experiments Division  
Code CE  
NASA Headquarters  
Washington, D.C. 20546



The early assembly of  
Space Station Freedom

***It's time for America  
to take its place  
on the final frontier***

1992

Design and text by TADCORPS  
Art by Harold Smelcer

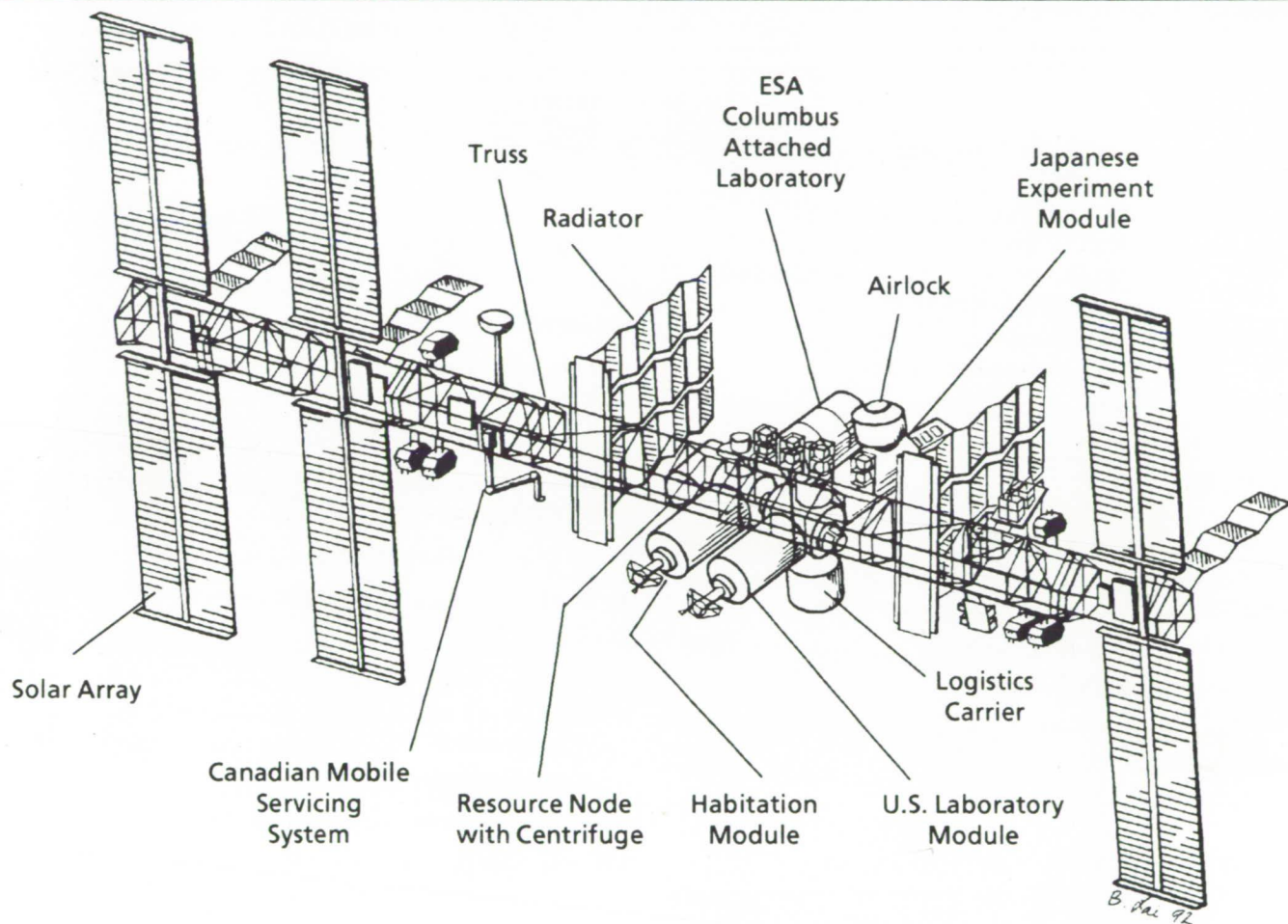


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## SPACE STATION FREEDOM OVERVIEW

*The mission of the Space Station Freedom Program is to build and operate an international, permanently inhabited, Earth-orbiting research facility in the late 1990s. Space Station Freedom is essential for advancing human exploration of space.*



### PURPOSE

Continued progress in the human exploration of space requires the development of a permanently inhabited space station for multi-year studies of human adaptation, testing of life support systems and experience in building, maintaining and operating a large, inhabited spacecraft. Space Station Freedom is America's essential next step for advancing human exploration of space.

Freedom will also serve as a permanent Earth-orbiting laboratory. It will allow humans the time and capabilities to routinely study, develop and employ the resources and potential of space for the benefit of humanity. Aboard Freedom, scientists and engineers will do work and perform research in the low-gravity environment of space for prolonged periods of time.

### GOALS OF THE SPACE STATION FREEDOM PROGRAM

- Establish a permanent human presence in space
- Enable human exploration of the solar system, including missions to the Moon and to Mars
- Enable scientific research and technology development
- Stimulate important technologies, such as automation and robotics
- Foster the development of commercial products and processes
- Study Earth on a continuous, global scale
- Promote education in science and engineering



## MISSION

The mission of the Space Station Freedom program is to:

- Provide a permanent outpost where we will learn to live and work productively in space.
- Provide an advanced research laboratory to explore space and employ its resources for the benefit of humanity.
- Provide the opportunity to learn to build, operate and maintain systems in space.

## COST

\$16.9 billion	Design, development, test and evaluation
\$5.0 billion	Other related costs, including Shuttle, assembly and utilization flights, construction of facilities and civil service personnel
\$7.7 billion	Operate and logistically support space station operations
\$8.0 billion	Furnished by international partners

## SCHEDULE

First Element Launch	1st Quarter 1996
Man-Tended Capability (U.S. Laboratory Module)	2nd Quarter 1997
Japanese Laboratory Module Launch	1998
ESA Laboratory Module Launch	1998
Habitation Module Launch	1999
Permanently Manned Capability	2000

## INTERNATIONAL PARTICIPATION

UNITED STATES	PARTNERS
<ul style="list-style-type: none"> <li>▶ Airlocks</li> <li>▶ Cupola</li> <li>▶ Habitation Module</li> <li>▶ Laboratory Module</li> <li>▶ Resource Nodes</li> <li>▶ Major Subsystems: Power, Thermal, Data</li> <li>▶ Mobile Transporter</li> <li>▶ Pressurized Logistics Module</li> <li>▶ Truss</li> <li>▶ Unpressurized Logistics Carrier</li> </ul>	<p><b>Japan</b></p> <ul style="list-style-type: none"> <li>▶ Japanese Experiment Module (JEM), including an exposed facility and an experiment logistics module</li> </ul> <p><b>European Space Agency</b></p> <ul style="list-style-type: none"> <li>▶ Attached Pressurized Module (APM)</li> <li>▶ Man-Tended Free-Flyer</li> </ul> <p><b>Canada</b></p> <ul style="list-style-type: none"> <li>▶ Mobile Servicing System (MSS)</li> </ul>

## SPECIFICATIONS

- End-to-end length: 108 meters (353 feet)
- Three laboratories
  - One U.S. laboratory: 8.4 meters (27.4 feet) long by 4.4 meters (14.5 feet) in diameter
  - One European laboratory: 11.8 meters (38.7 feet) long by 4.5 meters (14.7 feet) in diameter
  - One Japanese laboratory: 10.6 meters (34.8 feet) long by 4.0 meters (13.1 feet) in diameter
- One U.S. habitat (same dimensions as the U.S. laboratory)
- International Standard Payload Racks: 1 meter (3.5 feet) wide
- Three U.S. resource nodes: 5.2 meters (17 feet) long by 4.4 meters (14.5 feet) in diameter
  - Centrifuge in third resource node
- Canadian Mobile Servicing System
- Japanese Exposed Facility: 5.0 meters (16.4 feet) long by 5.6 meters (18.4 feet) wide
- ESA Columbus Free-Flying Laboratory
- Solar arrays: 12 meters (39 feet) wide and 34 meters (112 feet) long
- Number of cells per array wing: 32,800
- Number of solar cells for six array wings: 196,800
- Power generation: 18.75 kilowatts per array wing pair
- Total power available: 56.25 kilowatts, growing to 75 kilowatts in the Follow-on Phase, 120 volts DC
  - 30 kilowatts for researchers
  - 26.25 kilowatts for housekeeping
- Crew: four persons, two dedicated for payload operations, growing to eight crew in the Follow-on Phase
- Weight: 281,430 kilograms (310 tons)
- Altitude: 335-460 kilometers (208-285 statute miles)
- Inclination: 28.5 degrees to the Equator

***For further information, contact:***

***Spacelab/Space Station Utilization Program  
Code MG  
NASA Headquarters  
Washington, D.C. 20546***





## TECHNOLOGY

*The NASA Office of Aeronautics and Space Technology is responsible for planning and managing programs that will provide advanced technology in support of continued U.S. leadership in space. Space Station Freedom will provide the ideal facility for the long-term experimentation that is so vital to the advancement of engineering research.*

### TECHNOLOGY DEVELOPMENT IN SPACE

Each space venture has accomplished specific mission objectives and allowed us to evaluate new technologies for use in future NASA missions. The unique environmental conditions to which these enabling technologies are subjected on-orbit frequently cannot be fully or economically simulated on the ground. Some technologies must be validated in actual space conditions to reduce design margins, improve technology transfer, and reduce the risk during the development and use of these technologies. Unless new technologies can be validated in the space environment and shown to be affordable with low risk, project managers will continue to be reluctant to incorporate them into their products.

In order to facilitate transfer of technologies to flight projects, a balanced program of studies, laboratory experimentation, ground simulations and flight demonstrations is vital. In addition, the opportunities for in-space experimentation are expanding. With the arrival of Space Station Freedom in the late 1990s, NASA will have a research and development facility that can identify and develop technologies that are critical for future national space missions.

There are 11 broad areas in which in-space experimentation is expected to obtain vital data that cannot be collected on the ground or to prove the feasibility of advanced technologies.

**Space Construction.** Future space missions will require systems of ever-increasing size, complexity and sophistication. Space structures that are too large to be launched in a fully-integrated configuration will be required by these missions. In order to perform on-orbit construction of large space structures, we will have to increase our understanding of construction techniques and the fundamental changes in systems dynamics in a zero-g environment.

Since most large-scale structures are not self supporting in a one-g environment, ground-based construction techniques will have to be adapted and verified in space before they can be used to assemble vehicles, platforms and other structural components.

**Dynamics and Control.** Planetary exploration or lunar or Mars base development will potentially require spacecraft and systems that are larger and more complex than any existing space platforms. This will include the structural components of the vehicle itself, as well as the large-scale antennae and solar panel structures that will be required. In order to ensure that these vehicles and platforms perform acceptably, we must understand the dynamic behavior of very large-scale structures in space and devise techniques to control their dynamic response.



Assembling space structures

**Space Environmental Effects.** With plans for extended space missions on Space Station Freedom and other long-duration spacecraft, the characteristics of the space environment must be closely studied. Understanding the low-Earth orbit environment in terms of atomic oxygen, debris and electromagnetic radiation is crucial to the development of sensors, materials and coatings used in long-duration space missions.

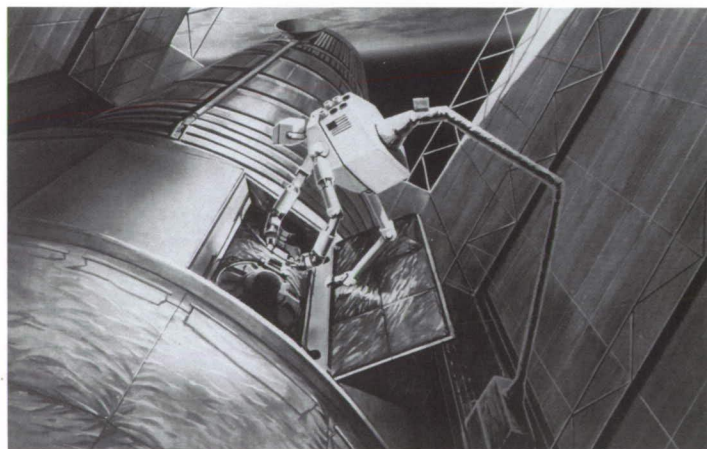
**Space Power Systems.** Future NASA missions will require the use of space power systems that can deliver high-capacity power reliably and efficiently. Solar dynamic and nuclear power will be a necessity for Earth-observing missions, materials processing platforms, geosynchronous communications platforms, planetary rovers, space transfer vehicles, lunar and Mars outposts, and interplanetary travel.



**Thermal Management.** Careful management of thermal energy in spacecraft is required to provide appropriate environmental conditions for humans and living organisms, to maintain spacecraft systems within design specifications, and to provide precise temperature control of onboard experiments. Thermal management in space requires the acquisition, transport and rejection of heat, as well as system integration.

**Fluid Management.** The handling, transportation, and on-orbit storage of cryogenic fluids are major technology areas in which advances can shape our future in space. Future large-scale missions will require space-based resupply tankers and transfer vehicles. Large quantities of cryogenic fuels and other liquefied gases will need to be pumped and stored in reduced gravity. The requirements for storage in low gravity may extend from several months to several years.

**Propulsion.** No single propulsion system will meet the needs of future long-duration and long-distance space goals, such as a manned Mars mission. These needs include increased spacecraft life and minimization of fuel and logistics. Extensive theoretical and experimental work is needed to make advanced propulsion systems a practical reality. Most propulsion systems will require on-orbit validation to evaluate performance and to determine impacts on spacecraft and payloads.



**Robots can perform high risk tasks in space**

**Automation and Robotics.** Robots for future space missions must be robust and provide safe manipulation and locomotion. Research is needed in the areas of control laws, collision avoidance, dynamics of coupling to a platform, use of task models, adaptive control and sensors for local autonomy. Robots must also contain fault-tolerant hardware and software. Artificial intelligence will also be needed to support the wide range of science and exploration missions now under consideration.

**Sensors.** Future space missions will have many advanced sensor requirements. These include low-Earth orbit environment-hardened and fault-tolerant sensors for applications ranging from acceleration measurement

to laser sensing of ozone, acid rain, water and carbon dioxide. Testing of sensor systems and subsystems in-space will be necessary to demonstrate their capability to operate reliably for an extended period. It will also be important to test the operation of the pointing, control and stabilization hardware for the sensors in reduced gravity.

**Information Systems.** New approaches must be taken to meet the communication requirements of future missions, including development of high-resolution sensors which generate very high data rates. Optical communication systems using semiconductor diode laser transmitters offer the potential for enormous size reductions and essentially unlimited bandwidth capabilities. Data relays among satellites are ideally suited to this revolutionary technology. A lunar base would require high rate data links with a relay station to enable communication with probes on the far side of the moon; proposed experiments to penetrate the Sun's plasma, deep space probes to 1000 astronomical units, and planetary missions will also need optical data systems.

**Human Systems Engineering.** New exploration missions call for the development of advanced human-centered technology. For long-duration missions, a mutual dependency between humans and the systems they use will exist to a far greater degree than in all prior history. Human-centered automation technology is needed to obtain overall mission reliability and productivity for crew members in space.

As humans learn to live and work in space for extended periods of time preparatory to exploration missions beyond Earth orbit, advanced life support systems will be developed. Space Station Freedom will be an ideal testbed for the development and validation of advanced life support components and subsystems leading to a completely closed, regenerable life support system suitable for supporting humans on advanced, long duration missions.

In the near term, the Space Shuttle will be the in-space testbed to develop innovative technologies to support the construction and operation of Space Station Freedom. In turn, Freedom will become the in-space test facility for the development of technologies needed for a lunar base, a piloted mission to Mars, and the continued robotic exploration of the solar system.

***For further information, contact:***

*Dr. Judith H. Ambrus  
NASA Headquarters  
Office of Aeronautics and Space Technology  
Code RSX  
Washington, D.C. 20546*



## SCIENCE

*Space Station Freedom represents an enormous opportunity to use the unique environment of space to perform life sciences and microgravity research. Science experiments will study life and its processes under the influence of different environmental conditions, and expand our knowledge of physics, chemistry, biotechnology, and materials and fluid sciences.*

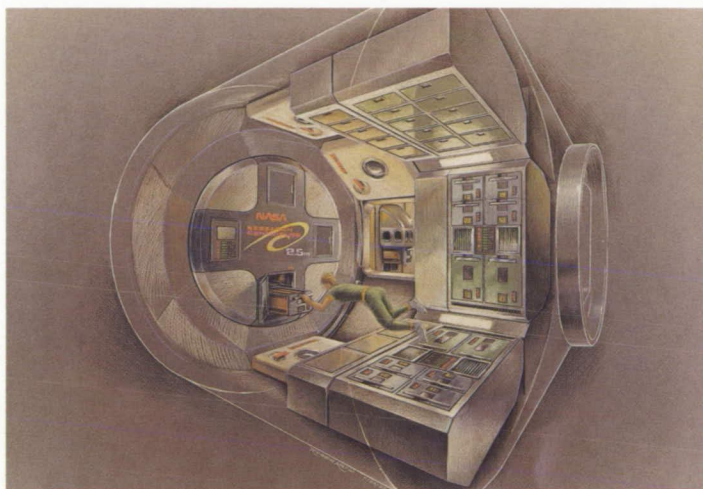
### LIFE SCIENCES RESEARCH ON FREEDOM

Through the space program, the universe has become an accessible domain, opening unprecedented possibilities for probing life processes. Our experience has taught us that in order to assure the health and safety of humans who undertake space missions, a comprehensive life sciences research program is necessary. Space Station Freedom is important to the NASA space life sciences programs that are developed and implemented by the Life Sciences Division of the Office of Space Science and Applications (OSSA). For the first time, it will be possible to study substantial numbers and types of specimens with appropriate controls and real-time analytical capabilities for extended periods.

Space Station Freedom will have a suite of life sciences facilities consisting of a 2.5-meter Centrifuge, a Biomedical Monitoring and Countermeasures Facility, a Gravitational Biology Facility, a Gas-Grain Simulation Facility and a Controlled Ecological Life Support System Test Facility. Two of these facilities are described below.

**Centrifuge Facility.** The Centrifuge is expected to be the single most important research tool for space life sciences. It will be used primarily to conduct basic research to determine the influence of gravity and radiation on biological systems, and eventually, to develop countermeasures necessary for long-duration human activity in space. The Centrifuge Facility will accommodate the diverse requirements of a wide variety of biological investigations using animals, plants, cells and tissue cultures. The effects of the space environment on reproduction, development and maturation of living systems will be of particular interest. Scientists will learn how long-duration space flight affects living systems over single and multiple generations. The Centrifuge Facility will also be used to examine the need for artificial gravity in long-duration human space missions.

**Controlled Ecological Life Support System (CELSS) Test Facility.** This facility will have the capability to control, monitor and evaluate the growth of food crops in a low gravity environment. The long on-orbit time on Space Station Freedom will allow scientists to study plant populations and behaviors throughout complete life cycles and over many generations. Results will be used to identify candidate crops for future life support, to determine how well the experiment subsystems work, and to pinpoint plant growth techniques that yield the highest quality and quantity of crops.



2.5-meter Centrifuge

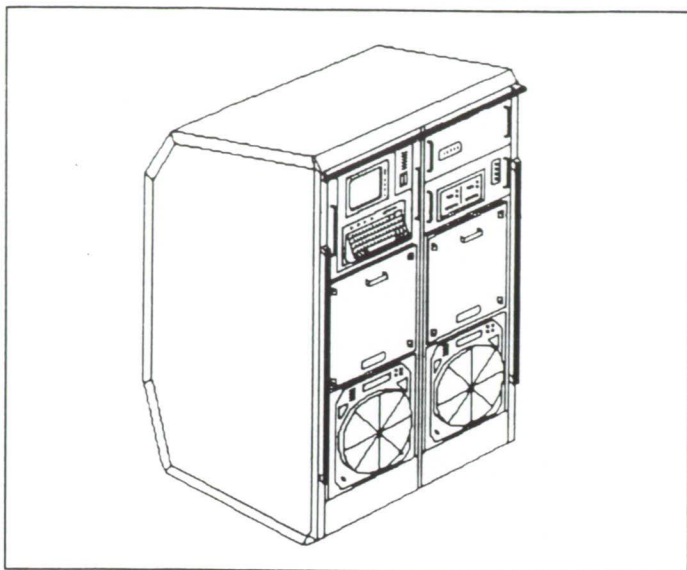
### LIFE SCIENCES RESEARCH PLANS

The space life sciences research strategy for the utilization of Space Station Freedom is an evolutionary process of facility development and phased deployment. In the beginning, the primary focus will be on understanding physiological responses to the low-gravity space environment. Various studies, including pulmonary, cardiovascular, anthropometric, metabolic, muscular and neurophysiological investigations will also be conducted.

Later, the Gravitation Biology, Gas-Grain Simulation and CELSS Test Facilities will be installed on Freedom. After checkout and verification, selected experiments in plant biology, cellular biology and gas-grain accretion studies will be performed in these facilities. Biomedical and research activities will be continued during this phase to expand our understanding of basic human physiologic adaptations to weightlessness. At the end of this period, the 2.5-meter diameter Centrifuge and associated hardware will be delivered to Freedom for checkout.

By the time humans occupy Space Station Freedom on a permanent basis, the life sciences facilities will be fully operational and ready for maximum utilization. The life sciences suite of equipment will be designed to support scientific investigations in many life sciences disciplines for more than 20 years. Included is the development and testing of an operational bioregenerative life support system and a Centrifuge Facility capable of supporting rodents and other small animals in artificial gravity and microgravity environments.





**Advanced Protein Crystal Growth Facility**

## **MICROGRAVITY RESEARCH ON SPACE STATION FREEDOM**

NASA's microgravity research program is a comprehensive study of materials science, biotechnology and the fundamental sciences in the space environment.

- Fundamental sciences study the behavior of fluids and transport phenomena, condensed matter physics and combustion science. The precision measurements possible in microgravity may challenge contemporary theories of relativity.
- Materials science includes the processing of electronic and photonic materials; metals, alloys and composites; glasses and ceramics; and polymers. The primary objective is a better understanding of how gravity-driven convection affects the processing of materials. The experiments should provide dramatic improvements in such materials and evolve new processing technologies that take full advantage of the microgravity environment. Production of limited quantities of exotic new materials, with superior properties, that can serve as benchmarks or be used for certain strategic applications, should be possible. Eventually, such efforts could lead to commercially viable enterprises.
- Biotechnology research focuses primarily on the growth of protein crystals. Space-grown protein crystals could have enormous implications for understanding the biological function of important proteins at the molecular level. In addition to fundamental knowledge, such information provides the basis for rational drug design, the development of new vaccines and protein engineering. Other possible research includes cell culturing, cell separation and cell fusion in microgravity.

The microgravity program, administered by OSSA's Microgravity Science and Applications Division (MSAD), promotes new technologies, materials and processes relevant to basic research and commercial applications, and facilitates the transfer of the technology and know how resulting from microgravity research to industry. Space Station Freedom will be an important research facility for testing our current understanding of microgravity phenomena. On Freedom, scientists will be able to conduct microgravity experiments in an interactive mode and feed the results of one set of experiments into the next set in a timely manner.

Currently, the microgravity program encompasses six concepts for space station facilities that will support microgravity research. The six facilities are: Advanced Protein Crystal Growth Facility, Biotechnology Facility, Fluid Physics/Dynamics Facility, Modular Combustion Facility, Modular Containerless Processing Facility, and the Space Station Furnace Facility. Each facility is modular in construction to provide the flexibility needed to support a large number of different scientific investigations, and to accommodate upgrades as new equipment and techniques become available. Two of these facilities are described below.

**Advanced Protein Crystal Growth Facility.** This facility will support biotechnology research by growing large macromolecular protein crystals with a high degree of internal order. Crystals remain free-floating during the growth period. Candidate proteins will be selected from 20,000 that have been appropriately characterized. These experiments will help determine the three-dimensional structure of complex molecules and will establish a better understanding of the physical process of protein crystallization.

**Space Station Furnace Facility.** This facility will accommodate solidification research in electro-optic materials, metals and alloys, composite materials, and glasses and ceramics. Apparatus optimized to perform melt, vapor and solution crystal growth will be included, as well as instruments to perform thermophysical property measurement of materials and directional solidification of metals and alloys.

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## RESEARCH ON SPACE STATION FREEDOM

*Space Station Freedom will offer human-assisted, long-duration experimentation in a permanently orbiting spacecraft. From the beginning, Freedom has been designed to accommodate researchers' needs. NASA's intention is to use Freedom's capabilities to the fullest extent possible for scientific research, technology development and commercial activities.*

### SPACE STATION FREEDOM RESEARCHERS

Researchers will come from schools and universities, research institutions, private companies, NASA and other government agencies. The three broad categories of space station researchers are:

- **Scientists** will study fundamental theories in areas such as fluid behavior and transport phenomena, flame propagation and the effects of low gravity on humans, animals, plants and materials. The results will expand our knowledge in such areas as crystal growth, fluid mechanics, combustion phenomena, human physiology and gravitational biology. The results may also aid in the treatment of human diseases while increasing our understanding of human physiology and plant development.
- **Technology developers** will examine structures, space environmental effects, noise and vibration, energy systems, propulsion, integrated circuits, automation and robotics and life support systems. These technologies will nurture innovation in Earth-based industries and future space missions.
- **Commercial organizations** will perform research with valuable applications in the medical, agricultural, chemical and food production industries for use on Earth and in space.

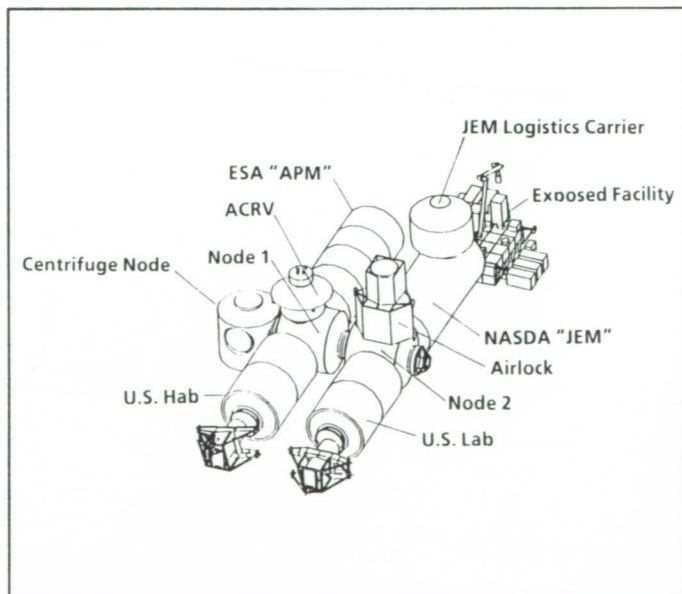
NASA has established offices that will sponsor users in these three areas. Working with the user communities, these offices are responsible for supporting research programs and evaluating and selecting candidate payloads for Freedom. Payloads will be developed for both the pressurized space station interior and for the unpressurized environment of Freedom's exterior. Payloads will be operated in orbit by the astronauts and by ground-based researchers using a sophisticated communications system.

### RESEARCH CAPABILITIES

The Space Station Freedom Program has worked with potential researchers to identify the research requirements Freedom needs to satisfy. The resulting design is a modular configuration that will begin modestly and grow in capability and size to satisfy new requirements as they evolve over time. Freedom will support research at all phases of its 30-year life in orbit.

The utilization plans now being developed by NASA will ensure that Freedom's research capabilities are used efficiently to advance our knowledge and improve life on Earth. The unprecedented research capabilities available when the space station is fully occupied include:

- 44 experiment racks (the size of large refrigerators)
- 30 kilowatts of electric power (eight times more than Spacelab)
- Four crew members with two crew members dedicated full-time to research
- Data transmission rates of 50 megabits per second
- High-speed computers with fiber optic communications links
- Long-duration missions
- Exterior experiments with power and communications ports.



Freedom's pressurized research laboratories

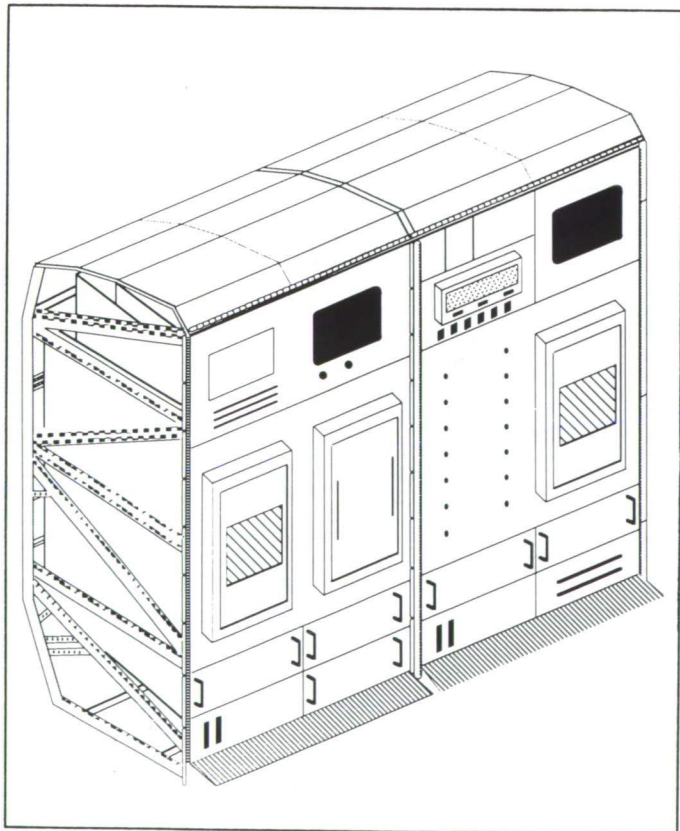


## PAYLOAD ACCOMMODATIONS

**Interior payloads.** The basic accommodation for payloads in the three pressurized laboratories is the International Standard Payload Rack (ISPR). A great enhancement to Freedom's overall utility is the modular design of these racks, which can be removed and replaced, as necessary, with other racks containing different experiment equipment. When a payload's "tour of duty" is complete, it will be removed from the laboratory and returned to Earth.

The outer dimensions of the ISPR are 6.5 feet (2 meters) high, 3.5 feet (107 centimeters) deep and 3.5 feet (107 centimeters) wide. Payloads may be accommodated in standard 19-inch (49-centimeter) drawers or double width drawers. The racks and attachment features are common throughout space station to allow payloads to be interchanged among the three international laboratories as needed.

**Exterior payloads.** Space Station Freedom will accommodate payloads that use the space environment to perform observational research. Two sites on the station's truss structure will be able to accommodate payloads in 1997, and four in 1999. Power and data services will be provided through standard ports located at the truss attached payload sites. Observational payloads will also be accommodated on the Japanese Experiment Module's Exposed Facility. The JEM Exposed Facility can accommodate 10 small to moderately sized payloads. Five of these sites are allocated to the United States.



An instrumented ISPR

## FREEDOM'S RESEARCH CAPABILITIES

### *Man-tended Phase (Spring 1997)*

- Fully outfitted U.S. laboratory to support life sciences and materials research
- Human-assisted research (13 days) while the Shuttle is docked
- 12 International Standard Payload Racks available for research equipment
- Two attachment points on the truss for external payloads
- Canadian Mobile Servicing Center and a mobile transporter
- Average power of 13,000 watts for researchers
- 50 million bits per second data downlink
- Regular Shuttle visits to perform space station research, three per year, until permanently manned
- Operates in a free-flyer mode when unattended, providing an undisturbed microgravity environment for automated and remotely controlled payloads

### *Permanently Manned Phase (Early 2000)*

- Fully outfitted U.S., European and Japanese laboratories
- Fully outfitted U.S. habitation module
- Year-round life sciences, microgravity and technology research
- 42 International Standard Payload Racks, 26 available to U.S. researchers
- Total power of 56,250 watts, with 30,000 watts average power for users
- Four-person permanent crew with two crew members dedicated to experiments
- Four attachment points on the truss for exposed payloads
- Accommodations for a 2.5-meter (8.2-foot) diameter centrifuge on the first Shuttle flight after Permanently Manned Capability
- Regular Shuttle resupply visits, four to five per year

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## THE MICROGRAVITY ENVIRONMENT OF SPACE

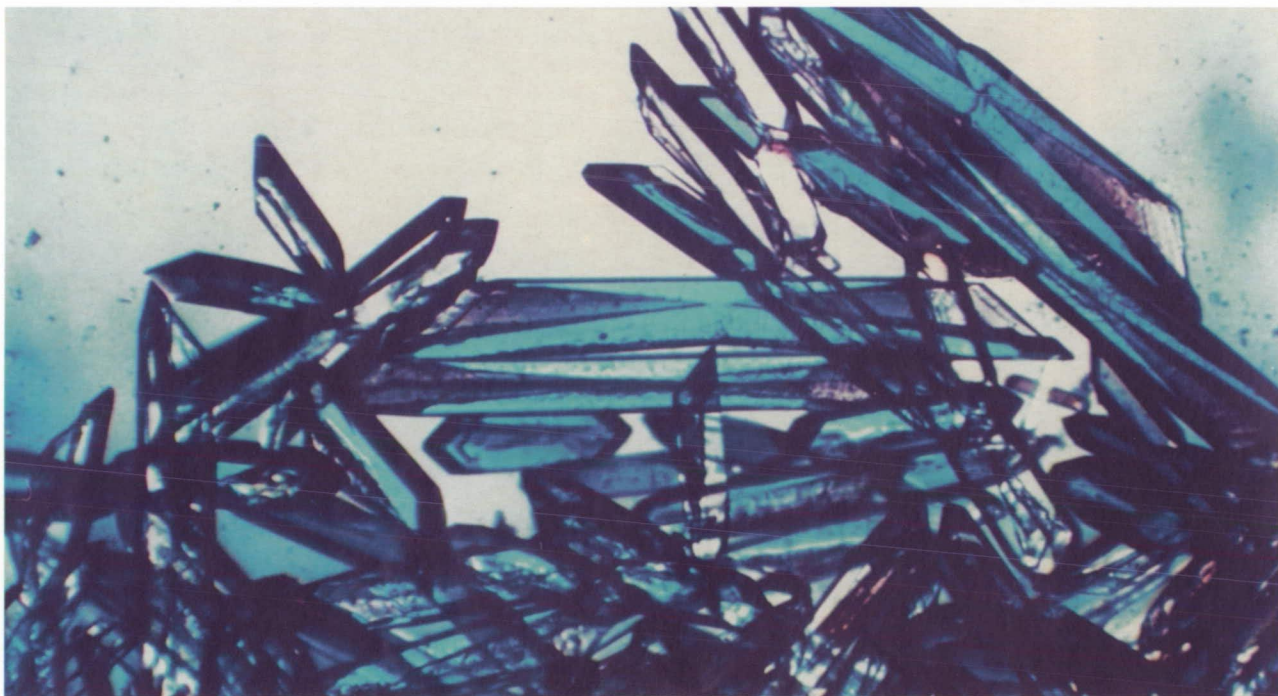
*The low-gravity environment of Space Station Freedom offers researchers the opportunity to study materials, processes and biological systems in ways that are not possible on Earth. From this research, scientists, technologists and commercial companies will gain important information to advance scientific goals and technological innovations for the benefit of life on Earth.*

### WHAT IS MICROGRAVITY?

The presence of Earth creates a gravitational field that acts to attract an object with a force inversely proportional to the square of the distance between the center of the object and the center of Earth. When measured at sea level on the surface of Earth, the acceleration of an object acted upon only by Earth's gravity is commonly referred to as "one g" or, "one Earth gravity"; this acceleration is approximately 9.8 meters per second squared ( $\text{m/s}^2$ ).

A microgravity environment then, using the first, broader definition above, will impart to an object a net acceleration that is "small" compared with that produced at Earth's surface. In practice, such accelerations will range from about one percent of Earth's gravitational acceleration (aboard aircraft in parabolic flight) to better than one part in a million (for example, aboard Earth-orbiting free-flyers). By the second definition, the acceleration imparted will be *exactly* one millionth ( $10^{-6}$ ) of that measured at Earth's surface.

The term *microgravity* can be interpreted and used in a number of ways depending on the context. The prefix, micro-, is derived from the original Greek *mikros*, meaning "small". Another common usage of micro- is found in quantitative systems of measurement such as the metric system, where micro- means *one part in a million*.



Insulin crystals grown in space

ORIGINAL PAGE  
COLOR PHOTOGRAPH



## MICROGRAVITY RESEARCH

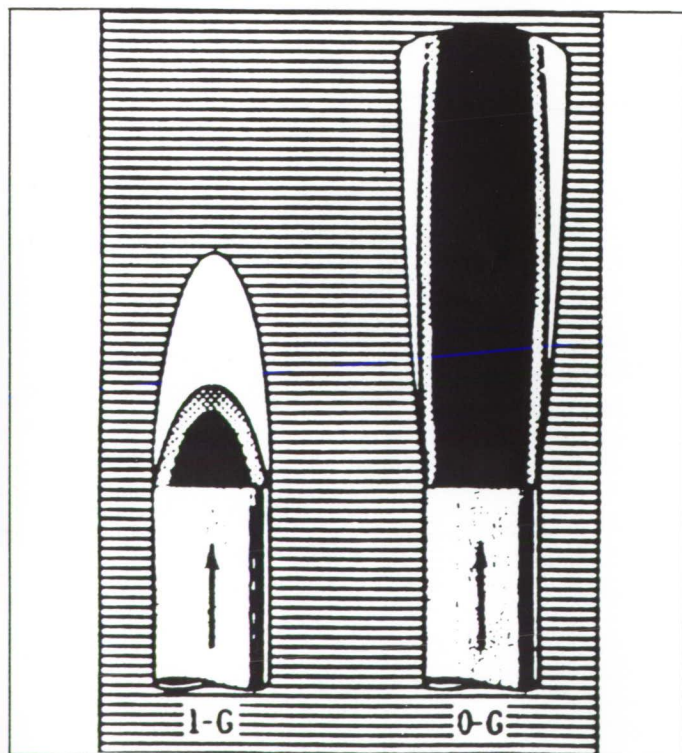
Low-gravity research on the ground has produced many beneficial discoveries by utilizing low acceleration environments for short periods. For example, using "drop towers," experiments fall, and are in, "weightlessness" for up to 10 seconds; parabolic flights of NASA's research airplane are in 30 seconds of weightlessness.

## MICROGRAVITY EXPERIMENTS ON SPACE STATION FREEDOM

**Life sciences experiments.** The many life sciences experiments planned for Freedom will study human, animal and plant life under the influence of different environmental conditions. For example, human physiology research will help us understand the effects of microgravity on the heart, skeleton, muscles and immune system of human beings.

**Protein crystal growth experiments.** Protein crystals are studied in space to understand the process by which they crystallize. Protein crystals can be used to give us knowledge of their structure, which in turn may aid in the development of new pharmaceuticals for treating human diseases.

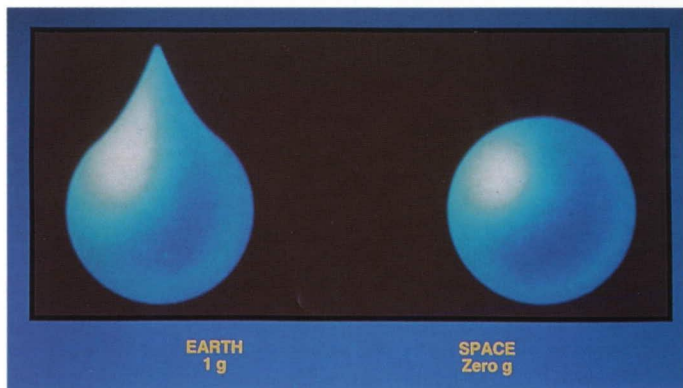
**Combustion experiments.** Combustion involves the release of large amounts of chemical energy. On Earth, gravity causes air currents near flames, feeding the flame with oxygen and removing heat. In space, the lack of convection changes the way flames behave, allowing researchers to study how flames spread, smolder and stop.



Combustion research in space

**Materials science experiments.** Space Station Freedom will permit thorough scientific research into materials used to produce semiconductors, metals, alloys, composite materials, glasses and ceramics. In microgravity, these materials can be cultivated with fewer defects than those developed on Earth. This will allow device designers to enhance the utility of devices we use today and to create new ones.

**Containerless processing experiments.** Microgravity permits some materials to be processed without being confined by a container. Under these conditions, solidification can be suppressed until the material is cooled far below its normal freezing point. This phenomenon can result in unique alloys and glasses.



Water droplet on Earth (left) and in space (right)

**Fluid behavior experiments.** The behavior of fluids is greatly affected by the presence of gravity. Studies on Space Station Freedom will result in an understanding of fluid flows, heat transfer, mass transfer and their effects. This understanding will provide the basic scientific and practical knowledge needed to design space-based systems and facilities that rely on fluid processes. The understanding will also provide the fundamentals for Space Station Freedom research in materials processing and combustion.

**Biological systems experiments.** Since gravity plays a major role in the development of most, if not all, biological systems, station experiments will focus on identifying the organ or site of gravity reception, on determining the effect of gravity on reproduction, development and evolution; and on investigating physiological responses to gravity.

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## BENEFITS OF SPACE STATION FREEDOM

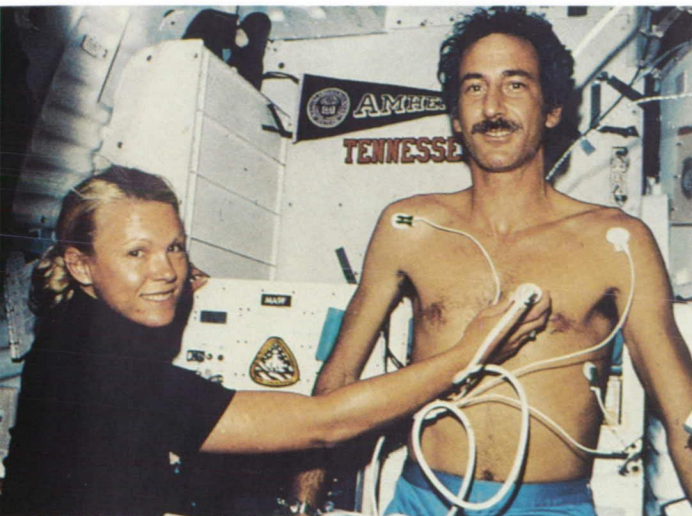
*Space Station Freedom will be an unprecedented facility for first-class basic and applied research in life sciences, microgravity research and technology development. This research will assist us in our commitment to improve the quality of life on Earth and achieve our national goal of world leadership in space.*

### RESEARCH BENEFITS

Access to the microgravity environment of space is one of the most important features of Space Station Freedom. Currently, U.S. researchers using the Shuttle are only able to visit space for a few days at a time. The station, expected to be in orbit for 30 years, will provide a laboratory in space for low-gravity experiments over a period of months or years. This continuous, stable laboratory environment is expected to yield many new developments in materials, electronics, medicine and the treatment of disease.

Our new research outpost in space, unsurpassed in providing power and volume for orbiting experiments, will have the constant presence of a human crew to make use of the microgravity environment. The specific disciplines that will benefit from Space Station Freedom are life sciences, microgravity research and technology development.

**Life sciences.** Life scientists will work to gain valuable information about the basic biological processes of cells, plants, animals and humans. The underlying knowledge about living organisms gained from experimentation in a controlled gravity environment will be a benefit in itself. Scientists are expected to apply this knowledge to enhance treatment and countermeasures that will be necessary to prepare future astronauts for long-duration space flight.



Human biological experiments in space

**Microgravity research.** Scientific experiments on the characteristics of fluids, metals, ceramics and other materials will expand our knowledge of how materials behave when they are unconstrained by gravity. This research will advance the basic science objectives of microgravity research. Commercial organizations may apply the knowledge gained to develop new communications systems and improve computer memories, sensors and solar cells. Space may be the site of unique developments in compound semiconductors, synthesized metallic materials and composites, and high temperature superconductors, for use on Earth and in space. Commercial organizations plan to grow defect-free protein crystals in orbit for use by the medical, agricultural and chemical industries. The potential of this research to increase the quality of life on Earth is enormous, ranging from the development of new pharmaceuticals to the protein enrichment of some foods.



CAT scan technology originated from space research

**Technology development.** The testing of technologies in space will investigate how microgravity, radiation and other aspects of the environment affect mechanical functions. For example, research into the support systems for human spaceflight may enable long-term human space exploration and provide new advances for life on Earth. Systems designed for the station can be potentially adapted for water and air purification systems used on Earth. To date, space program technology has improved human health care by contributing to the development of insulin delivery systems, pacemakers, CAT scans, thermal video systems to supplement X-rays and many others.



Technology development will focus on constructing advanced space systems for easier and cheaper access to outer space, improved spacecraft designs, and robotics for conducting high-risk or monotonous tasks in space.

Automation and robotics technologies have already proven to be of interest to commercial entities for application on Earth. Much of the activity in this area will focus on developing technologies that can enhance the efficient operation and use of Space Station Freedom.



Computer-aided physics training developed by NASA

## EDUCATION BENEFITS

Space Station Freedom will yield benefits not only to those directly involved in using it, although the scientific and research gains are expected to be momentous. Space captures the minds and hearts of the U.S. public, and the imagination and pride of our children. The magic, the wonderment of it, has the ability to inspire.

In speaking of the importance of space programs, the NASA Administrator recently commented that "Our programs . . . airplanes, spaceships, moon, Mars and astronauts . . . can get to kids. Ghosts can do it, dinosaurs can do it, and space can do it. I believe no other benefit of this endeavor will loom so large."

Space Station Freedom will stimulate the interest of our youth and encourage them to study science, math and engineering, and influence teachers who view space as a learning tool. One of the most significant benefits of Space Station Freedom may be its ability to revitalize America's competitiveness in the classroom and industry for years to come.

From the vantage point of space, Space Station Freedom will also provide us with new insights into ourselves and our potential to improve life for all inhabitants of Earth. We can then build on this awareness to meet the continuing challenges of future space exploration and our stewardship of Earth.

## ECONOMIC BENEFITS

Historically, our investment in space has proven to be a wise one. Space Station Freedom will continue this tradition by contributing research and information that will enhance the quality of life on Earth. Research conducted on Freedom will be the source of better medical treatments, improved medicines, innovative products and new services developed or tested in space. Freedom will also be an important return on hard-earned tax dollars. Studies have shown that investing in high technology research and development programs such as the space station return more to the economy, over time, than the initial investment. The money spent to build and operate Space Station Freedom will be spent on Earth, not in space.

## INTERNATIONAL COOPERATION

Influential members of the U.S. Congress realized as early as 1957 that a strong national space program offered a base for international cooperation in activities that could extend peaceful pursuits on a worldwide frontier. Space Station Freedom is the largest international space venture ever undertaken.

Freedom will promote international cooperation in scientific endeavors that are of mutual benefit. Scientific and technological resources and equipment will be shared among many countries.

Space Station Freedom will also expand research opportunities for U.S. scientists by sharing costs and information. It will serve as an international learning center where many countries will be able to work together peacefully and use the resources of space for the benefit of all.



Freedom's international partners

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**NASA**



## COMMERCIAL SPACE

*Space Station Freedom presents two areas of opportunity for commercial development: utilization and infrastructure. Commercial utilization includes research, development and testing of materials or technologies using Freedom's research capabilities. Commercial infrastructure involves developing systems and services for Freedom's users on a for-profit basis.*

### COMMERCIAL UTILIZATION

Utilization of Space Station Freedom's facilities and capabilities will allow commercial organizations to take advantage of the unique characteristics of the space environment for research and development of technologies, processes and products, and for the testing of products. Although the Space Shuttle provides short-term access to this environment, Space Station Freedom will enable long-term, continuous utilization of space.

To the fullest extent possible, the Space Station Freedom Program will provide commercial users with the facilities and services necessary to conduct experiments on Freedom. There are two types of commercial users: commercial cooperative users, sponsored by the NASA Office of Commercial Programs (OCP), and commercial reimbursable users, sponsored by the NASA Office of Space Flight.

**Commercial Cooperative Utilization.** Users who engage in commercial activities that are partially funded by NASA are known as *commercial cooperative users*. The primary point of entry into the program is through the Centers for the Commercial Development of Space (CCDSs). The CCDS program consists of 17 Centers based at universities and research institutions across the country that work with industry and NASA to conduct space-based, high technology research. OCP selects the Centers and provides annual funding of up to \$1 million. The Centers receive additional financial and in-kind contributions from industrial affiliates, with a goal of increasing reliance on industrial sponsorship. NASA also provides the Centers with scientific and technical expertise, opportunities for cooperative activities and other forms of continuing assistance.

The 17 CCDSs represent eight major research areas. Four CCDSs are dedicated to materials processing research; three to biomedical and biotechnology research; two to remote sensing; two to automation and robotics; one to space propulsion; one to space structures and materials; two to space power research; and two to communications technology research.

In a relatively short time, the CCDSs have fostered private-sector investment and participation in commercial space ventures. More than 175 industrial affiliates and 72 university participants are exploring the economic potential of space in this program, which allows technical and financial risks to be shared.



Space is an international marketplace

NASA also sponsors joint agreements with industry that are negotiated with OCP. Through these agreements, NASA provides assistance, services and facilities to help reduce the risks associated with commercial space ventures. Each agreement offers different opportunities in return for some type of compensation or quid pro quo arrangement. OCP's review of a proposed activity focuses on the project's technical merit, the industry's commitment to the activity, and the accommodations and resources required from both the sponsor and NASA to support the project.

**Commercial Reimbursable Utilization.** Users whose commercial activities are completely self-funded are known as *commercial reimbursable users*. They work with the Office of Space Flight to develop their payload plans. After a user submits a Request for Flight, other required documentation and a predetermined amount of earnest money, the necessary resources will be reserved and evaluation of the request will begin. A compatibility analysis will be performed and, if the payload can be accommodated by the station, negotiations will begin. The negotiations will result in a Space Station Utilization Services Agreement between the program and the user. This is a legal contract consisting of the terms and conditions for the delivery of the payload by the sponsor and the provision of services by NASA. It includes the identification and quantification of services to be provided, schedules, price and financial arrangements, insurance provisions, liability provisions, etc.



**Commercial Payloads on Space Station Freedom.** Potential commercial payloads, or research experiments conducted on orbit, are already being identified for Space Station Freedom. Protein crystals grown in the microgravity environment of the station are expected to have many commercial applications in the medical, agricultural and chemical industries. Some of the potential applications are new pharmaceuticals for the treatment of human diseases; increased success of organ transplants and implants; the development of pesticides to improve crops; and enhanced protein nutrition in some foods. New companies have already been formed to exploit this industrial research activity.

Research into the production of zeolites on Space Station Freedom are of interest to commercial users representing a wide range of industrial applications. Zeolites are crystals with microscopic tunnels that allow them to be used in many industrial processes. The chemical processing industry and the biotechnology industry will be interested in these crystals, particularly if they can be grown in significant quantities. Space-grown zeolite crystals could result in the development of portable kidney dialysis machines, improved industrial chemical processes and improved methods for handling radioactive waste.

Station experiments into the purification and recycling of water using plant systems could spawn new technologies for closed-loop water systems required by space facilities and spur innovations in novel terrestrial applications. In space, long-term inhabited facilities will require recycling and purification of water to increase the efficiency of life support systems. On Earth, commercial organizations can use this research to develop new methods for removing contaminants from industrial effluents that continue to menace our ground water supplies.

Commercial users are also planning to provide an environment for the growth of plants on Space Station Freedom, to explore how plants grow and develop without the effect of gravity. This research will examine the feasibility of growing food in space, to benefit current agricultural research and future long-term space flight.

In the area of automation and robotics, software applications, robotic devices and artificial intelligence systems being developed for use on the station can be applied to ground-based industry. Industries that present hazards to humans are already being evaluated as areas for commercial applications of space-based research.

## **COMMERCIAL INFRASTRUCTURE**

Commercial infrastructure involves the development or operation of systems and services for users of Space Station Freedom on a for-profit basis. Future phases of the station will offer the private sector the opportunity to provide commercial infrastructure to NASA and other users of the space station. Companies that build on the baseline station in order to provide new systems and services will then benefit from opportunities for extensive technology development, new markets and long-term profits.

The Space Station Freedom Program will facilitate this commercial participation by being a long-term customer for the infrastructure, awarding companies long-term franchises for systems and services, and providing technical assistance whenever possible. This relationship will assist U.S. industry by promoting international competitiveness. It will also help the program if additional resources can be identified to help fund Freedom's development. The private sector can be an important source of expert advice on approaches to reduce operational cost, increase safety and productivity and plan future growth.

Just as ground-based businesses require infrastructure in the form of buildings, power, transportation and communications services, Space Station Freedom crews and users will need similar types of infrastructure. The buildings in this case will be the station's pressurized modules; transportation will be provided by the Space Shuttle and possibly expendable launch vehicles; and communications will require voice and high-speed data transmission services, via satellite. Because of the high risk, the government will provide the initial infrastructure, but once the risk has been lowered, industry may provide additional station infrastructure.

The market for infrastructure systems or services will be NASA, other U.S. government users, commercial users, and the Space Station Freedom international partners (Japan, the European Space Agency and Canada). Greater opportunities will generally exist for those services for which the market extends beyond the U.S. government.

A company developing a commercial service will maintain ownership and control of its infrastructure elements and pricing methods. As benefits, industry will receive entry into an emerging market, long-term profits and return on investment, access to new technology, and market expansion.

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